

# OBJECTIVE LENS DRIVE APPARATUS FOR USE IN OPTICAL PICKUP

## Background of the Invention

The present invention relates to an objective lens drive  
5 apparatus for use in an optical pickup forming an optical disk  
unit which projects an optical spot onto a record medium to  
be able to read information out of the record medium optically.

An optical pickup forming an optical disk unit is generally  
composed of an objective lens drive apparatus including an  
10 objective lens and an optical system for transmitting the light  
to the objective lens and receiving the light therefrom, while  
the objective lens drive apparatus is disposed on an optical  
system block mounting table. The objective lens drive apparatus  
is composed of a movable part including an objective lens,  
15 a focus coil and a tracking coil, and a fixed part including  
a magnetic circuit; and, the movable part is supported on the  
fixed part by four wires each of which is in part surrounded  
and held by an elastic damper member such as a visco-elastic  
member.

20 As an objective lens drive apparatus which not only can  
drive an objective lens in a focus direction and in a tracking  
direction but also can correct the coma and astigmatism of  
a spot which is image formed on a disk, there is known an apparatus  
which is disclosed in Japanese Patent Publication No. Hei.  
25 9-231595. This conventional device is characterized in that,





are disposed square-shaped flat coils 1104 for tracking drive by twos, a total of four coils 1104. Also, on the two mutually opposing surfaces of the lens holder 1101 in the optical disk radial direction (R), as the coils 1105 for inclination correction, there are disposed a pair of square-shaped flat coils; and, above and below the coils 1105 for inclination correction, there are disposed printed circuit boards (not shown) which are supported through copper foil portions 1115, 1116.

On an actuator base 1108, there are projectingly provided yoke portions 1109, 1110; and, the yoke portions 1109, 1110, through magnets 1111, 1112, form a substantially closed magnetic circuit for focus-direction and tracking-direction driving.

Also, on the two side surfaces of the actuator base 1108, there are disposed two side yokes 1113, 1114 for lens holder inclination adjustment drive, the top plan views of which respectively show a horseshoe shape. And, in each of the side yokes 1113, 1114, there are disposed long magnets 1106 and 1107 of mutually reversed polarities in such a manner that they correspond to the upper and lower sides of the coils 1105 for inclination correction.

Also, on the actuator base 1108, similarly to the above, there are further disposed square-shaped printed circuit boards 1117, 1118 through copper foil portions 1119, 1120. And, four spring wires 1121 of phosphor bronze are connected to the lens holder 1101 in such a manner that the spring wires 1121 are

respectively fixed by printed circuit boards disposed on the two ends of the spring wires 1121; and thus, the lens holder 1101 is supported elastically by the spring wires 1121 (as for the fixation of the spring wires 1121, see the plan view shown in Fig. 40).

In Fig. 38, reference character F designates a focus axis of a moving system of an objective lens actuator, R stands for a tracking axis thereof, and T represents an optical disk tangent axis thereof.

Next, description will be given below of the inclination drive of the lens holder 1101 according to the related art with reference to Fig. 39. In case where the current directions of the coils 1105 for right and left inclination correction respectively disposed on the optical-disk-radial-direction two side surfaces of the lens holder 1101 are set in the same direction and the magnetic field directions of the left and right magnets 1106 and 1107 disposed so as to correspond to the upper and lower sides of the coils 1105 for inclination correction are set symmetrical, the electromagnetic driving forces of the right and left coils are different in direction from each other according to Fleming's rule (see arrow marks F, F' in Fig. 39). Therefore, while the center of gravity or center of support of the lens holder 1101 is present substantially at the same point, in case where the lens holder 1101 is rotated about this point, the inclination of the objective lens with

respect to the optical disk 1100 can be corrected.

However, in the above-mentioned conventional technique, in order to correct the inclination of the objective lens, separately from the coils and magnets for tracking servo and focus servo, there must be further disposed the coils 1105 and magnets 1106, 1107 for inclination correction, which results in the increased cost of the objective lens drive apparatus.

Also, in the conventional technique, the coils 1105 and magnets 1106, 1107 for inclination correction must be disposed on the optical-disk-1100 radial direction side surfaces of the lens holder 1101 holding the objective lens 1103, which results in the increased width and weight of the objective lens drive apparatus.

#### Summary of the Invention

The present invention aims at solving the above problems found in the conventional technique.

Now, description will be given below of first aspect of the invention for solving the above problems with reference to Fig. 1 which corresponds to a first embodiment of the invention.

According to the first aspect, within the same magnetic gap 5g of a magnetic circuit having at least one magnet 5 magnetized in multi-polarities, there is disposed a coil unit 3 on which a focus coil 3f, tracking coils 3tr and tilt coils 3ti are mounted.

In the first aspect, the magnet 5 magnetized in multi-polarities is used to make a correction of the inclination of an objective lens, which can eliminate the need for provision of an exclusive magnet exclusively used to correct the above-mentioned objective lens inclination.

Also, description will be given below of second aspect of the invention for solving the above problems with reference to Fig. 20 which corresponds to a second embodiment of the invention. According to the second the second aspect, there are completed two magnetic circuits each having at least one magnet 105 magnetized in multi-polarities and, within the magnetic gap 105g of each of the two magnetic circuits, there is disposed a coil unit 103 on which a focus coil 103f, tracking coils 103tr and tilt coils 103ti are mounted.

In the second aspect, the magnet 105 magnetized in multi-polarities is used to make a correction of the inclination of an objective lens, which can eliminate the need for provision of an exclusive magnet exclusively used to correct the objective lens inclination.

Further, description will be given below of third aspect of the invention for solving the above problems with reference to Fig. 27 which corresponds to a third embodiment of the invention.

According to the third aspect, there is provided an objective lens drive apparatus for use in an optical pickup which detects the inclination of an optical disk and adjusts the inclination

of an objective lens in accordance with an optical disk inclination signal, wherein, within the same magnetic gap 205g of a magnetic circuit having at least one magnet 205 magnetized in multi-polarities, there is disposed a coil unit 203 on which  
5 a plurality of focus coils 203fl, 203fr and tracking coils 203t are mounted. Currents are respectively supplied to the plurality of focus coils 203fl, 203fr and, due to the sum of the driving forces of the focus coils 203fl, 203fr, focus servo is executed. Due to the difference between the above driving  
10 forces, there is produced moment around the center of gravity of a movable part and the inclination of the objective lens 202 can be thereby adjusted simultaneously with the focus servo operation.

In the third aspect, due to the operations of the plurality  
15 of focus coils 203fl and 203fr, not only the focus servo but also the adjustment of the inclination of the objective lens 202 can be executed.

#### Brief Description of the Drawings

20 Fig. 1 is an exploded perspective view of a first embodiment of an objective lens drive apparatus for use in an optical pickup according to the invention;

Fig. 2 is a side view of a magnetic circuit employed in the first embodiment according to the invention;

25 Fig. 3 is an arrangement view of the first embodiment,

showing the position relationship between magnets and focus coils/tracking coils at the self-weight position of the first embodiment in the focus direction;

Fig. 4 is an arrangement view of the first embodiment,  
5 showing the position relationship between magnets and tilt coils at the self-weight position of the first embodiment in the focus direction;

Fig. 5 is an arrangement view of a modification of the first embodiment, showing the position relationship between  
10 magnets and tilt coils at the self-weight position of the modification in the focus direction;

Fig. 6 is a plan view of a magnetic circuit employed in the modification of the first embodiment;

Fig. 7 is an arrangement view of the modification, showing  
15 the position relationship between magnets and focus coils/tracking coils at the self-weight position of the modification in the focus direction;

Fig. 8 shows of a modification of a coil unit of the first embodiment;

20 Fig. 9 is an exploded perspective view of another modification of the first embodiment;

Fig. 10 is a plan view of a magnetic circuit employed in the objective lens drive apparatus shown in Fig. 9;

Fig. 11 is an arrangement view to show the position  
25 relationship between a magnet having four poles magnetized

and tracking coils according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 12 is an arrangement view to show the position  
5 relationship between a magnet having four poles magnetized and focus coils according to the example shown in Fig. 11, in the own weight position of this example in the focus direction;

Fig. 13 is an arrangement view to show the position  
10 relationship between a magnet having four poles magnetized and tilt coils according to the example shown in Figs. 11 and 12, in the own weight position of this example in the focus direction;

Fig. 14 is an arrangement view to show the position  
15 relationship between a magnet having three poles magnetized and focus coils/tracking coils according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 15 is an arrangement view to show the position  
20 relationship between a magnet having three poles magnetized and tilt coils according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 16 is an arrangement view to show the position  
25 relationship between a magnet having three poles magnetized and focus coils/tracking coils other example of the first

embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 17 is an arrangement view to show the position relationship between a magnet having three poles magnetized and tilt coils according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 18 is an arrangement view to show the position relationship between a magnet having three poles magnetized and focus coils/tracking coils/tilt coils according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction;

Fig. 19 is an arrangement view of the position relationship between a magnet having two poles magnetized and focus coils/tracking coils/tilt coil according to other example of the first embodiment of the invention, in the own weight position of this example in the focus direction.

Fig. 20 is an exploded perspective view of a second embodiment of an objective lens drive apparatus for use in an optical pickup according to the invention;

Fig. 21 is an exploded perspective view of a modification of the second embodiment;

Figs. 22A and 22B are plan views of a magnetic circuit employed in the objective lens drive apparatus shown in Fig.

9;

Fig. 23 is an exploded perspective view of another modification of the second embodiment;

Fig. 24 is a front view of the objective lens drive apparatus shown in Fig. 23;

5 Fig. 25 is an arrangement view of the modification of the second embodiment shown in Fig. 23, showing the position relationship between magnets and tracking coils/tilt coils at the self-weight position of the second embodiment in the focus direction;

10 Fig. 26 is an arrangement view of the modification of the second embodiment shown in Fig. 23, showing the position relationship between magnets and tracking coils/tilt coils at the self-weight position of the second embodiment in the focus direction;

15 Fig. 27 is an exploded perspective view of a third embodiment of an objective lens drive apparatus for use in an optical pickup according to the invention;

Fig. 28 is an arrangement view of the third embodiment, showing the position relationship between magnets and focus  
20 coils/tracking coils at the self-weight position of the third embodiment in the focus direction;

Fig. 29 is a block diagram of a circuit configuration for focus servo and inclination drive employed in the third embodiment of the invention;

25 Fig. 30 is an explanatory view of the focus servo and

inclination drive to be executed in the third embodiment;  
specifically, Fig. 30A shows a case where there are produced  
driving forces having the same direction; and, Fig. 30B shows  
a case where there are produced driving forces respectively  
5 having reversed directions;

Fig. 31 is an exploded perspective view of a modification  
of the third embodiment;

Fig. 32 is an arrangement view of the modification of  
the third embodiment, showing the position relationship between  
10 magnets and focus coils/tracking coils at the self-weight  
position of the modification in the focus direction;

Fig. 33 is an arrangement view of other example of the  
third embodiment of an objective lens drive apparatus for  
use in an optical pickup according to the invention, showing  
15 the position relationship between a magnet having four poles  
magnetized and tracking coils, in the own weight position  
of this example in the focus direction;

Fig. 34 is an arrangement view of the example shown in  
Fig. 33 to show the position relationship between a magnet  
20 having four poles magnetized and focus coils, in the own weight  
position of this example in the focus direction;

Fig. 35 is an arrangement view of other example of the  
third embodiment of an objective lens drive apparatus for  
use in an optical pickup according to the invention, showing  
25 the position relationship between a magnet having three poles

magnetized and focus coils/tracking coils, in the own weight position of this example in the focus direction;

Fig. 36 is an arrangement view of other example of the third embodiment, showing the position relationship between  
5 a magnet having three poles magnetized and focus coils/tracking coils, in the own weight position of this example in the focus direction;

Fig. 37 is an arrangement view of other example of the third embodiment, showing the position relationship between  
10 a magnet having three poles magnetized and focus coils/tracking coils, in the own weight position of this example in the focus direction;

Fig. 38 is an exploded perspective view of a conventional objective lens drive apparatus;

15 Fig. 39 is an explanatory view of an inclination correction driving operation to be executed in the conventional objective lens drive apparatus;

Fig. 40 is a plan view of an actuator employed in the conventional objective lens drive apparatus; and,

20 Fig. 41 is a block diagram of the configuration of a circuit employed in the conventional objective lens drive apparatus to execute the tilt servo.

#### Detailed Description of the Preferred Embodiments

25 (Embodiment 1)

Now, Fig. 1 is an exploded perspective view of a first embodiment of an objective lens drive apparatus for use in an optical pickup according to the invention. In Fig. 1, reference character 1 designates a lens holder, 2 an objective lens, 3 a coil unit, 3f a focus coil, 3tr a tracking coil, 3ti a tilt coil, 5 a magnet, and 5g a magnetic gap, respectively.

The lens holder 1 is formed of light metal of high modulus of flexural elasticity, for example, magnesium alloy, or resin mixed with carbon fibers. Use of such material allows the lens holder 1 itself to have higher flexural elasticity modulus and thus have higher high-order resonance frequencies. Due to this, the lens holder 1 is able to cope with an increase in the speed of an optical disk unit.

In the lens holder 1, there are formed two notch portions 1a which respectively extend in the tracking direction T. Also, an objective lens mounting portion 1b, which is also formed in the lens holder 1, is structured such that it is uniform in thickness.

Each of the two notch portions 1a has a surface on which there is formed an insulated protective film (not shown) for insulation reinforcement. The reason for provision of such insulated protective film is that, since light metal of high flexural elasticity modulus such as magnesium alloy or resin mixed with carbon fibers used as the material of the lens holder 1 is high in conductivity, the insulation of the coil unit

3 to be mounted on the notch portions 1a must be secured. In case where an insulated protective film for insulation reinforcement is not formed on the surfaces of the notch portions 1a of the lens holder 1, an insulated protective film (not shown) for insulation reinforcement may be formed on the portions of the coil unit 3 that are to be mounted onto the notch portions 1a to thereby be able to secure the insulation of the coil unit 3.

The coil unit 3 is a laminated coil unit which comprises:  
a required number of printed circuit boards 31 each having a pattern in which a focus coil 3f and four tracking coils 3tr are formed; and, a required number of printed circuit boards 32 in each of which two tilt coils 3ti are formed, whereby the two kinds of printed circuit boards 31 and 32 are alternately laminated one on top of another to thereby provide a pattern structure as a coil unit. The focus coil 3f is disposed in the central portion of the printed circuit board 31; and, the tracking coils 3tr are disposed right and left (in the tracking coil direction T) with respect to the position of the center of gravity of an objective-lens-optical-axis-direction movable part including the lens holder 1 holding the objective lens 2, that is, on the right and left sides of the focus coil 3f in two upper and lower stages. The four tracking coils 3tr are connected in series. By the way, the tracking coils 3tr may also be composed of two tracking coils. The two tilt coils

3ti are disposed right and left (in the tracking coil direction T) with respect to the center of the printed circuit board 32. The two tilt coils 3ti are connected in series.

The printed circuit boards 31 and 32 can be laminated one on top of another, for example, by holding the two side surfaces of a printed circuit board 32 between two printed circuit boards 31 in such a manner that they are arranged symmetric when they are viewed from the tracking direction T. In this case, drive points in the respective directions can be made coincident, thereby being able to avoid resonance (pitching resonance, yawing resonance) which would be possibly caused when the drive points are not coincident.

The foregoing description relates to the structure where the focus coil 3f and tracking coils 3tr are formed in each printed circuit board 31. However, the focus coil 3f and tracking coils 3tr may also be formed separately in two printed circuit boards. Further, as shown in Fig. 8, the coil unit 3' may have a printed circuit board 31' and a printed circuit board 32', wherein the focus coil 3f and tilt coils 3ti are formed on the printed circuit board 31', and the tracking coils 3tr are formed on the printed circuit board 32'. Fig. 8 shows four tracking coil 3ti are formed on the printed circuit board 32', however, two tracking coil 3ti may be formed on the printed circuit board 32'. In these structures as well, the printed circuit boards may be laid one on top of another so as to be

symmetric right and left when they are viewed from the tracking direction T, thus being able to avoid resonance by possibly caused when the drive points are not coincident.

The coil unit 3 is inserted into and bonded to the notch portions 1a so that it is fixed to the lens holder 1. In the two ends of the coil unit 3 in the tracking direction T, there are formed six V-grooves 3v, while one-end portions of six conductive elastic members 4 are respectively fixed by solder (not shown) to the six V-grooves 3v. In the case of the conductive elastic members 4 which serve as lead wires, two of them are used to drive the focus coils, two are used to drive the tracking coils, and two are used to drive the tilt coils: that is, a total of six conductive elastic members are provided. By the way, four conductive elastic members 4 are sufficient to elastically hold the lens holder 1 which serves as a movable part and, therefore, in case where four conductive elastic members 4 are used, lead wires (not shown) are to be connected to the remaining coils. However, by using four conductive elastic members 4 for driving the tilt coils, use of a flexible conductor, arrangement of a supporting member, and risk of contact with other members in driving can be avoided.

The magnet 5 is bonded to a yoke 7 disposed on a yoke base 6 in such a manner that the magnet 5 is magnetized in two polarities in the focus direction F by a boundary line 5b between the N and S poles of the magnet 5. As shown in Fig.

2, the boundary line 5b between the N and S poles is positioned at the center of the magnet 5 in the focus direction F, the mutually opposing arrangement of two magnets 5 forms a magnetic gap 5g between them, and, magnetic force lines B are reversed in direction in the focus direction F of the magnetic gap 5g.

By the way, as shown in Fig. 9, the magnetic circuit may include one magnet 5', and the coil unit may be disposed in the magnetic gap 5g'. Fig. 10 shows the magnetic circuit including the magnet 5', similar operation of coils in the case of providing the magnetic circuit including two magnets 5 and gap 5g described above can be obtained. Due to this, the whole objective lens drive apparatus can be made compact. Here, the magnetic gap means an air gap or an air path, in Fig. 9, the magnetic gap 5g' is formed by one magnet.

The width W of the magnet 5 is determined such that when the coil unit 3, as shown in Fig. 3, is disposed in the magnetic gap 5g at the movable neutral position of the movable part which is movably supported in a cantilevered manner by the conductive elastic members 4, that is, at the self-weight position of the movable part in the focus direction F, of the vertical sides A and C (which extend in parallel to the focus direction F) of the four tracking coils 3tr disposed right and left in the two upper and lower stages, the right and left inner vertical sides A and C can be disposed within the magnetic gap 5g (which points out a gap existing within the width W of the two mutually

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opposing magnets 5); and also, as shown in Fig. 4, of the vertical  
sides a' and c' (which extend in parallel to the focus direction  
F) of the two tilt coils 3ti disposed right and left in a row,  
the right and left outer vertical surfaces a' and c' can be  
5 disposed within the magnetic gap 5g. Also, the height H of  
the magnet 5 is determined such that, as shown in Fig. 3, the  
horizontal sides b and d (which extend perpendicularly to the  
focus direction F) of the single focus coil 3f disposed at  
the center of the printed circuit board 31 as well as the upper  
10 and lower outer horizontal sides B and D of the horizontal  
sides B and C (which extend perpendicularly to the focus direction  
F) of the tracking coils 3tr can be disposed within the magnetic  
gap 5g (which points out a gap existing within the height H  
of the two mutually opposing magnets 5); and also, as shown  
15 in Fig. 4, the horizontal sides b' and d' (which extend  
perpendicularly to the focus direction F) of the tilt coils  
3ti can be disposed within the magnetic gap 5g.

The boundary line 5b between the N and S poles of the  
magnet 5, as shown in Fig. 3, is situated midway between the  
20 lower side b and upper side d of the horizontal sides b, d  
(which extend perpendicularly to the focus direction F) of  
the focus coil 3f, midway between the lower side B of the horizontal  
sides B, D (which extend perpendicularly to the focus direction  
F) of the upper-stage tracking coil 3tr and the upper side  
25 D of the horizontal sides B, D (which extend perpendicularly

to the focus direction F) of the lower-stage tracking coil 3tr, and, as shown in Fig. 4, midway between the lower side b' and upper side d' of the horizontal sides b', d' (which extend perpendicularly to the focus direction F) of the tilt coils 3ti. The center of the magnet 5 is substantially coincident with the center of the coil unit 3.

The coil unit 3 is arranged in the magnetic gap 5g, while the other-end portions of the conductive elastic members 4 are respectively penetrated through a wire base 8 and are fixed to a base plate 9 by soldering. Due to this, the focus coil 3f, the tracking coil 3tr and the tilt coil 3ti mounted on the coil unit 3 can be disposed within the magnetic gap 105g and, at the same time, the movable part including the lens holder 1 holding the objective lens 2 is supported in a cantilevered manner so as to be movable with respect to the fixed part which includes the magnet 5, yoke base 6, yoke 7, wire base 8 and base plate 9.

In Fig. 3, in case where currents are allowed to flow in the tracking coils 3tr, due to the currents (shown by arrow marks) that flow in the vertical sides A, C which extend in parallel to the focus direction F) of the tracking coils 3tr, in the four tracking coils 3tr, there are generated driving forces in the same direction according to Fleming's left-hand rule. Also, in case where a current is allowed to flow in the focus coil 3f, due to the currents that flow in the horizontal

sides b, d (which extend perpendicularly to the focus direction F) of the focus coil 3f, in the focus coil 3f, there is generated a driving force in the focus direction F according to Fleming's left-hand rule.

5        In Fig. 4, in case where currents are allowed to flow in the tilt coils 3ti, due to the currents (shown by arrow marks) that flow in the horizontal sides b', d' (which extend perpendicularly to the focus direction F) of the tilt coils 3ti, in the two tilt coils 3ti, there are generated driving  
10    forces F' in the mutually reversed directions in the focus direction F according to Fleming's left-hand rule. Due to the mutually-reversed-direction driving forces F', there is generated moment around the center of gravity of the movable part to thereby be able to adjust the inclination of the lens  
15    holder 1 and thus the inclination of the objective lens 2.

As described above, in case where not only the focus coil 3f and tracking coils 3tr but also the tilt coils 3ti are arranged within the same magnetic gap 5g of the magnetic circuit including at least one magnet, not only focus servo and tracking servo  
20    but also tilt servo (that is, the adjustment of the inclination of the objective lens 2) can be carried out. This can eliminate the need for provision of a magnet which is exclusively used to adjust the inclination of the objective lens 2. Due to this, the number of parts can be reduced, the adjustment of the  
25    inclination of the objective lens 2 can be made at a low cost,

and the whole objective lens drive apparatus can be made compact.

The foregoing description relates to the structure in which the two tilt coils 3ti are arranged right and left (in the tracking direction T) with respect to the center of the printed circuit board 32. However, a similar effect can also be obtained even in a structure in which, as shown in Fig. 5, two tilt coils 3ti are arranged upward and downward (in the focus direction F) with respect to the center of the printed circuit board 32.

In this case, the coil unit 3 is structured such that, as shown in Fig. 7, a required number of printed circuit boards (not shown) each having a pattern including a tracking coil 3tr and four focus coils 3f and, as shown in Fig. 5, a required number of printed circuit boards (not shown) each having a pattern including two tilt coils 3ti are alternately laid one on top of another. One tracking coil 3tr is disposed in the central portion of the printed circuit board 31; and, four focus coils 3f are disposed in the right and left directions (in the tracking direction T) with respect to the position of the gravity of an objective-lens-optical-axis-direction of the movable part including the lens holder 1 holding the objective lens 2, that is, on the right and left sides of one tracking coil 3tr in two upper and lower stages. The four focus coils 3f are connected in series. The four focus coils 3f may also be replaced with two focus coils. The two tilt coils 103ti

are connected in series.

The foregoing description relates to the structure in which the focus coil 3f and tracking coils 3tr are disposed on the same printed circuit board. However, there can also  
5 be employed a structure in which focus coils 3f and tracking coils 3tr are separately disposed on two printed circuit boards.

In this case as well, the printed circuit boards are laid one on top of another so as to be symmetric right and left when they are viewed from the tracking direction T.

10 In this structure, the magnet 5, as shown in Fig. 6, is magnetized in two polarities in the tracking direction T by the boundary line 5b between the N and S poles of the magnet 5, and is bonded to the yoke 7 on the yoke base 6. As shown in Fig. 6, the boundary line 5b between the N and S poles is  
15 situated at the center of the magnet 5 in the tracking direction T, the magnetic gap 5g is formed due to the mutually opposing arrangement of the two magnets 5 and, in the magnetic gap 5g, the direction of a magnetic line of force B is reversed in the tracking direction T. By the way, alternatively, as shown  
20 in Figs. 9 and 10, instead of the two magnets 5, there may be used a single magnet 5. In this case, the boundary line 5b' between the N and S poles is situated at the center of the magnet 5 in the tracking direction T. Due to this, the whole objective lens drive apparatus can be made compact.

25 The width W of the magnet 5 is determined such that, as

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shown in Fig. 7, when the coil unit 3 is arranged in the magnetic gap 5g at the movable neutral position of the movable part movably supported in a cantilevered manner by the conductive elastic members 4, that is, at the self-weight position thereof

5 in the focus direction F, not only the right and left outer vertical sides a and c of the vertical sides a and c (which extend in parallel to the focus direction F) of the four focus coils 3f arranged right and left in two upper and lower stages but also, as shown in Fig. 5, the vertical sides a' and c'

10 (which extend in parallel to the focus direction F) of the two tilt coils 3ti arranged in two upper and lower stages can be respectively disposed within the magnetic gap 5g (which points out a gap existing within the width W of the mutually opposing magnets 5). Also, the height H of the magnets 5 is

15 determined such that not only, as shown in Fig. 7, the lower sides b of the horizontal sides b, d (which extend perpendicularly to the focus direction F) of the upper-stage focus coils 3f, the upper sides d of the horizontal sides b, d (which extend perpendicularly to the focus direction F) of the lower-stage

20 focus coils 3f, and the horizontal sides B and D (which extend perpendicularly to the focus direction F) of the tracking coil 3tr but also, as shown in Fig. 5, the upper sides d' of the horizontal sides b', d' (which extend perpendicularly to the focus direction F) of the upper-stage tilt coil 3ti and the

25 lower sides b' of the horizontal sides b', d' (which extend

perpendicularly to the focus direction F) of the lower-stage tilt coil 3ti can be respectively disposed within the magnetic gap 5g (which points out a gap existing within the height H of the mutually opposing magnets 5).

5           The boundary line 5b between the N and S poles of the magnet 5 is situated not only, as shown in Fig. 7, midway between the left sides c of the vertical sides a, c (which extend in parallel to the focus direction F) of the right focus coil 3f and the right sides a of the vertical sides a, c (which  
10       extend in parallel to the focus direction F) of the left focus coil 3f, and midway between the right side A and left side C of the vertical sides A, C (which extend in parallel to the focus direction F) of the tracking coil 3tr, but also with, as shown in Fig. 5, midway between the right side a' and left  
15       c' of vertical sides a', c' (which extend in parallel to the focus direction F) of the tilt coil 3ti. The center of the magnet 5 is substantially coincident with the center of the coil unit 3.

          In Fig. 7, in case where a current is allowed to flow  
20       in the tracking coil 3tr, due to the current (shown by an arrow mark) that flows in the vertical sides A, C (which extend in parallel to the focus direction F) of the tracking coil 3tr, in the tracking coil 3tr, there is generated a driving force in the tracking direction T according to Fleming's left-hand  
25       rule; and, in case where currents are allowed to flow in the

focus coils 3f, due to the currents (shown by arrow marks) that flow in the horizontal sides b, d (which extend perpendicularly to the focus direction F) of the focus coils 3f, in the four focus coils 3f, there are generated driving  
5 forces respectively having the same direction in the tracking direction T according to Fleming's left-hand rule.

In Fig. 5, in case where currents are allowed to flow in the tilt coils 3ti, due to the currents (shown by arrow marks) that flow in the vertical sides a', c' (which extend  
10 in parallel to the focus direction F) of the tilt coils 3ti, in the two tilt coils 3ti, there are generated driving forces in the mutually reversed directions in the tracking direction T according to Fleming's left-hand rule. Due to the reversed-direction driving forces, there is generated moment  
15 around the center of gravity of the movable part to thereby be able to adjust the inclination of the lens holder 1 and thus the inclination of the objective lens 2.

In this embodiment, the magnet 5 has two poles magnetized in the focus direction F or in the tracking direction T. However,  
20 this is not limitative but, for example, as shown in Fig. 11, the magnet 5 may include two magnet sections each having two poles magnetized in the tracking direction and respectively disposed in two upper and lower stages in the focus direction, whereby the magnet 5 has four poles magnetized. In this  
25 embodiment, as shown in Fig. 11, two tracking coils 3tr are

disposed in upper and lower stages, that is, in the first and second quadrants of the magnet 5 as well as in the third and fourth quadrants of the magnet 5; and, after then, in case where currents having opposite directions are allowed to flow through the two tracking coils 3tr, in the two tracking coils 3tr, there are generated drive forces having the same direction in the tracking direction T. Also, as shown in Fig. 12, two focus coils 3f are disposed in the right and left portions of the magnet 5, that is, in the first and fourth quadrants of the magnet 5 as well as in the second and third quadrants of the magnet 5; and, after then, in case where currents having opposite directions are allowed to flow through the two focus coils 3f, in the two tracking coils 3f, there are generated drive forces having the same direction in the focus direction F. Further, as shown in Fig. 13, two tilt coils 3ti are disposed in the right and left direction, that is, in the first and fourth quadrants of the magnet 5 as well as in the second and third quadrants of the magnet 5; and, after then, in case where currents having the same direction are allowed to flow through the two tilt coils 3ti, in the two tilt coils 3ti, there are generated drive forces  $F'$  having mutually opposite directions in the focus direction F. Due to these opposite-direction drive forces  $F'$ , there is generated the moment around the center of gravity of the movable part, which makes it possible to adjust the inclination of the lens

holder 1 and thus the inclination of the objective lens 2.

Although not shown, two tilt coils 3ti may be disposed not in the right and left portions of the magnet 5 but in the upper and lower stages thereof, that is, in the first and second quadrants of the magnet 5 as well as in the third and fourth quadrants of the magnet 5, and currents having the same direction are allowed to flow through the two tilt coils 3ti. In this case, in the two tilt coils 3ti, there are generated drive forces  $F'$  having mutually opposite directions in the tracking direction T. Due to these opposite-direction drive forces  $F'$ , there is generated the moment around the center of gravity of the movable part of the magnet 5, thereby being able to adjust the inclination of the lens holder 1 and thus the inclination of the objective lens 2.

In case where a magnet 5 is structured so as to have four poles magnetized, when compared with a magnet 5 having two poles magnetized, the number of coils is reduced from seven down to six and, therefore, the coils can be saved. Also, in the case of a magnet 5 having two poles magnetized, the portions of the coils, which are opposed to the portions for generation of the coil drive forces, must be disposed outside the magnetic gap 5g, (in Fig. 3, the A side and C side of the tracking coils 3tr; in Fig. 7, the b side and d side of the focus coils 3f). On the other hand, in the case of a magnet

having four poles magnetized, it is not necessary that the present portions are disposed outside the magnetic gap 5g, which makes it easy to arrange the coils. Also, in case where the whole portion of coils are disposed within the magnetic gap 5g, the two mutually opposed sides always contribute toward generating the coil drive forces, thereby being able to enhance the use rate of the coils.

In the above embodiments, the magnet 5 has two or four poles magnetized. However, this is not limitative but, for example, there can also be used a magnet which is structured such that, as shown in Fig. 14, one pole (for example, S pole) has an I-shaped front surface and two other poles (for example, N poles) each having a quadrilateral-shaped front surface are inserted into the other space of one pole to thereby provide a quadrilateral-shaped front surface as a whole; and thus, the magnet 5 has three poles magnetized. In this case, as shown in Fig. 14, in case where two tracking coils 3tr are disposed right and left, that is, in the web portion of the I-like shape and in the Npoles, and currents having the opposite directions are allowed to flow through the two tracking coils 3tr, in the two tracking coils 3tr, there are generated drive forces having the same direction in the tracking direction T. Also, as shown in Fig. 14, in case where four focus coils 3f are disposed in the right, left, upper and lower portions of the magnet 5, that is, in the upper and lower portions

of the flange portion of the I-like shape and in the N poles, and currents having the same direction are allowed to flow through the two focus coils 3f disposed in the upper stage and currents, the directions of which are the same but are  
5 opposite to the directions of the currents in the upper stage, are allowed to flow through the two focus coils 3f disposed in the lower stage, there are generated in the four focus coils 3f drive forces having the same direction in the focus direction F. Also, as shown in Fig. 15, in case where four  
10 tilt coils 3ti are disposed in the right, left, upper and lower portions of the magnet 5, that is, in the upper and lower portions of the flange portion of the I-like shape and in the N poles, currents having the opposite directions are allowed to flow through the two tilt coils 3ti disposed in  
15 the upper stage, and currents, the directions of which are opposite to each other and are opposite to the directions of the currents in the upper stage, are allowed to flow through the two tilt coils 3f disposed in the lower stage, there are generated in the right and left tilt coils 3ti drive forces  
20 F' having opposite directions in the focus direction F. Due to the drive forces F' having opposite directions, there is generated the moment around the center of gravity of the movable part, thereby being able to adjust the inclination of the lens holder 1 and thus the inclination of the objective lens  
25 2.

When the magnet 5 is structured such that it has three poles magnetized, as shown in Fig. 16, one pole (for example, S pole) may have an H-shaped front surface and the other two poles (for example, Npoles) each having a quadrilateral-shaped front surface may be inserted into the other space of one pole to thereby provide a magnet having a quadrilateral-shaped front surface as a whole. In this case, as shown in Fig. 16, in case where four tracking coils 3tr are disposed in the right, left, upper and lower portions of the magnet 5, that is, in the right and left portions of the flange portion of the H-like shape and in the Npoles, currents having the opposite directions are allowed to flow through the two tracking coils 3tr disposed in the upper stage, and currents, the directions of which are opposite to each other and are the same as the directions of the currents in the upper stage, are allowed to flow through the two tracking coils 3tr disposed in the lower stage, there are generated in the four tracking coils 3tr drive forces  $F'$  having the same direction in the tracking direction  $T$ . Also, as shown in Fig. 16, in case where two focus coils 3f are disposed in the upper and lower portions of the magnet 5, that is, in the web portions of the H-like shape and in the Npoles, and currents having opposite directions are allowed to flow through the two focus coils 3f, in the two focus coils 3f, there are generated drive forces having the same direction in the focus direction  $F$ . Also, as shown

in Fig. 17, in case where four tilt coils 3ti are disposed in the right, left, upper and lower portions of the magnet 5, that is, in the right and left portions of the flange portion of the H-like shape and in the N poles, currents having opposite directions are allowed to flow through the two tilt coils 3ti disposed in the upper stage, and currents, the directions of which are opposite to each other and are opposite to the directions of the currents in the upper stage, are allowed to flow through the two tilt coils 3ti disposed in the lower stage, there are generated in the upper and lower tilt coils 3ti drive forces  $F'$  having opposite directions in the tracking direction T. Due to the drive forces  $F'$  having opposite directions, there is generated the moment around the center of gravity of the movable part, thereby being able to adjust the inclination of the lens holder 1 and thus the inclination of the objective lens 2.

In this embodiment, there are used four tilt coils 3ti, two or four focus coils 3f and two or four tracking coils 3tr. However, in case where two tilt coils 3ti are used, as shown in Fig. 18, there can be used a magnet 5 as follows: that is, one pole (for example, S pole) has a T-shaped front surface and the other two poles (for example, N poles) each having a quadrilateral-shaped front surface are inserted into the other space of one pole to thereby provide a magnet 5 having a quadrilateral-shaped front surface as a whole; and

thus, the magnet 5 has three poles magnetized. In this case, two tracking coils 3tr are disposed in the central portion of the magnet 5, that is, in the vertical portion of the T shape and in the N poles, while two focus coil 3f and two tilt coils 3ti are disposed in the right and left portions of the magnet 5, that is, in the horizontal portion of the T-like shape and in the N poles.

Also, as shown in Fig. 19, there can also be used a magnet 5 as follows: that is, one pole (for example, S pole) has a U-shaped front surface and the other pole (for example, N pole) having a quadrilateral-shaped front surface is inserted into the other space of one pole to thereby provide a magnet having a quadrilateral-shaped front surface as a whole; and thus, the magnet 5 has two poles magnetized. In this case, one focus coil 3f is disposed in the central portion of the magnet 5, that is, in the horizontal portion of the U shape and in the N pole, while two tracking coils 3tr and two tilt coils 3ti are disposed in the right and left portions of the magnet 5, that is, in the vertical portions of the U shape and in the N pole.

In the case of a magnet having three poles magnetized, when compared with a magnet having two poles magnetized, similarly to a magnet having four poles magnetized, the coil arrangement can be facilitated and thus the use rate of the coils can be enhanced.

Thus, in the case of a two-pole magnetized magnet using a U shape, a three-pole magnetized magnet and a four-pole magnetized magnet, similarly to the two-pole magnetized magnet according to the previously described first embodiment, the coil unit includes a plurality of piled-up printed circuit boards of three individual types: that is, a first type of circuit board includes one or more focus coils 3f mounted thereon, a second type includes one or more tracking coils 3tr mounted thereon, and a third type includes one or more tilt coils 3ti are mounted. Also, the coil unit may include a plurality of piled-up printed circuit boards of two types: that is, a printed circuit board of one type includes one or more focus coils 3f and one or more tracking coils 3tr mounted thereon; and, a printed circuit board of the other type includes one or more tilt coils 3ti mounted thereon. Further, the coil unit may also include a plurality of piled-up printed circuit boards of two types: that is, a printed circuit board of one type includes one or more focus coils 3f and one or more tilt coils 3ti mounted thereon; and, a printed circuit board of the other type includes one or more tracking coils 3tr mounted thereon.

In the above-mentioned structures, including the cases of a two-pole magnetized magnet using a U shape, a three-pole magnetized magnet and a four-pole magnetized magnet, the magnetic gap 5g, as shown in Figs. 1, 2 and 6, may be defined

by a single magnet 5' as shown in Figs. 10 and 11.

(Embodiment 2)

Now, Fig. 20 is a perspective view of a second embodiment  
5 of an objective lens drive apparatus according to the invention.

In Fig. 20, reference character 101 designates a lens holder,  
102 an objective lens, 103 a coil unit, 103f a focus coil,  
103tr a tracking coil, 103ti a tilt coil, 105 a magnet, and  
105g a magnetic gap, respectively.

10 The lens holder 101 is made of light metal of high modulus  
of flexural elasticity, for example, magnesium alloy, or resin  
mixed with carbon fibers. Use of such material allows the lens  
holder 101 itself to have higher flexural elasticity modulus  
and thus have higher high-order resonance frequencies. Due  
15 to this, the lens holder 101 is able to cope with an increase  
in the speed of an optical disk unit.

Referring further to the structure of the lens holder  
101, on the plane surface thereof, there are formed two slits  
111 through which a magnet 105 and a yoke 107 (both of which  
20 will be discussed later) can be inserted; on the central portion  
of the lens holder 101, there is mounted the objective lens  
102; on each of a pair of side surfaces of the lens holder  
101 which extend at right angles to the tracking direction  
T, there are projectingly disposed two upper and lower support  
25 pieces 112 to which the one-end portions of conductive elastic

members 104 (which will also be discussed later) can be fixed; and, to a pair of side surfaces of the lens holder 101 which extend in parallel to the tracking direction T, there are fixed coil units 103 (which will also be discussed later).

5           Insulated protective films (not shown) for reinforcement are respectively formed on the surfaces of the pair of side surfaces (which extend in parallel to the tracking direction T) of the lens holder 101. The reason for provision of such insulated protective films is to secure the insulation of the  
10 coil units 103 to be mounted onto the lens holder 101 because light metal of high modulus of flexural elasticity, for example, magnesium alloy, or resin mixed with carbon fibers used as the material of the lens holder 101 is high in conductivity.

In case where such insulated protective films for reinforcement  
15 are not formed on the surfaces of the pair of side surfaces (which extend in parallel to the tracking direction T) of the lens holder 101, insulated protective films (not shown) for reinforcement may be formed on the portions of the coil units 103 that are to be mounted onto the lens holder 101, thereby  
20 securing the insulation of the coil units 103.

Referring now to the coil unit 103, a required number of printed circuit plates 131 each having a pattern composed of a focus coil 103f and four tracking coils 103tr and a required number of printed circuit plates 132 each having a pattern  
25 composed of two tilt coils 103ti are laminated or laid one

on top of another to thereby form the coil unit 103. The focus coil 103f is disposed in the central portion of the printed circuit board 131; and, the tracking coils 103tr are disposed in the right and left directions (in the tracking direction T) with respect to the position of the center of gravity of an objective-lens-optical-axis-direction movable part including the lens holder 101 holding the objective lens 102, that is, on the right and left sides of the focus coil 103f in two upper and lower stages. The four tracking coils 103tr are connected in series. By the way, the four tracking coils 103tr may also be replaced with two tracking coils. The two tilt coils 103ti are disposed in a row right and left (in the tracking coil direction T) with respect to the center of the printed circuit board 32. The two tilt coils 103ti are connected in series.

The printed circuit boards 131 and 132 may be laminated in such a manner that the two side surfaces (which extend in parallel to the tracking direction T) of the printed circuit board 131 and the two side surfaces (which extend in parallel to the tracking direction T) of the printed circuit board 132 are arranged symmetric when they are viewed from the tracking direction T, for example, the printed circuit board 131 is arranged inside on the objective lens 102 side and the printed circuit board 132 is arranged outside on the objective lens 102 side. In this case, drive points in the respective directions

can be made coincident with each other, thereby being able to avoid resonance (pitching resonance, yawing resonance) which would be possibly caused when the drive points are not coincident.

The foregoing description relates to the structure in which the focus coil 103f and tracking coils 103tr are formed in the same printed circuit board 131. However, the focus coil 3f and tracking coils 3tr may also be formed separately in two different printed circuit boards. Further, as shown in Fig. 8, the coil unit 3' may have a printed circuit board 31' and a printed circuit board 32', wherein the focus coil 3f and tilt coils 3ti are formed on the printed circuit board 31', and the tracking coils 3tr are formed on the printed circuit board 32'. Fig. 8 shows four tracking coil 3ti are formed on the printed circuit board 32', however, two tracking coil 3ti may be formed on the printed circuit board 32'. In these case as well, the printed circuit boards may be laid one on top of another symmetrically right and left when they are viewed from the tracking direction T, thus being able to avoid resonance by possibly caused when the drive points are not coincident.

The one-end portions of the four conductive elastic members 104 are respectively fixed by solder (not shown) to the support pieces 112 of the lens holder 101 with the coil units 103 fixed thereto. Two lead wires are necessary to drive the focus coils, two lead wires are necessary to drive the tracking coils, and two lead wires are necessary to drive the tilt coils, that

is, a total of six lead wires are necessary. Here, four units of such conductive elastic member 104 are enough to elastically support the lens holder 101 serving as the movable part. Here, the conductive elastic members 104 can also be used as lead  
5 wires. Therefore, the four conductive elastic members 104 are used as four of the six lead wires, while other lead wires (not shown) are connected to the remaining coils.

The two coil units 103 are respectively arranged in the two magnetic gaps 105g, while the other-end portions of the  
10 conductive elastic members 104 are respectively penetrated through a wire base 108 and are fixed to a base plate 109 by soldering. Due to this, the focus coil 103f, tracking coils 103tr and tilt coils 103ti mounted on the coil unit 103 can be disposed within the magnetic gap 105g and, at the same time,  
15 the movable part including the lens holder 101 holding the objective lens 2 is supported in a cantilevered manner so as to be movable with respect to the fixed part which includes the magnet 105, yoke base 106, yoke 7, wire base 108 and base plate 109.

20 The structures of the magnetic circuits employed in the apparatus shown in Fig. 20 as well as the arrangements and operations of the focus coils, tracking coils and tilt coils used in the coil units of the apparatus shown in Fig. 20 are similar to the previously described first embodiment and thus  
25 the description thereof is omitted here (see Figs. 2 to 4).

FIG. 4

As described above, according to the present embodiment, there are completed two magnetic circuits each including at least one magnet 105 magnetized in two polarities, and, within the magnetic gap 105g of each of the two magnetic circuits 5 105, there are disposed not only the focus coil 103f and tracking coils 103tr but also the tilt coils 103ti. Thanks to this, not only focus servo and tracking servo but also tilt servo (that is, the adjustment of the inclination of the objective lens 102) can be attained. Therefore, there is eliminated the 10 need for provision of a magnet which is exclusively used to adjust the inclination of the objective lens 102. This can reduce the number of parts, can adjust the inclination of the objective lens 102 at a low cost, and can reduce the size of the whole objective lens drive apparatus.

15 The above description relates to the structure in which the two tilt coils 103ti are respectively disposed right and left (in the tracking direction T) with respect to the center of the printed circuit board 132. However, similarly to the first embodiment, even in case where the two tilt coils 103ti 20 are respectively disposed upwardly and downwardly (in the focus direction F) of the center of the printed circuit board 132, there can be obtained a similar effect. In this case, the structure of the magnetic circuit and the operation of the coil unit are similar to the first embodiment and thus the 25 description thereof is omitted here (see Figs. 5 to 7).

Further, as well as the first embodiment, four tracking coils 103tr may be formed on the printed circuit board 131, and one focus coil 103f and two tilt coils 103ti may be formed on the printed circuit board 132. (see Figs. 8 and 9)

Furthermore, in this embodiment, the magnet 5 has two poles magnetized in the focus direction F or in the tracking direction T. However, as well as the first embodiment, the coils may be disposed in the magnetic gap defined by the two-pole magnetized magnet using a U shape, the three-pole magnetized magnet and the four-pole magnetized magnet. (see Figs. 11 to 19)

By the way, as shown in Fig. 21, two magnetic circuits may respectively include one magnet 105'. In this case, magnets 105' and yokes 107' are respectively provided outside of a lens holder 101' with respect to the center of the lens holder 101'. In this structure, the slit 111 need not be provided in the lens holder 101', therefore, the whole objective lens drive apparatus can be made compact. The magnetic circuit in this case is shown in Figs. 22 or 22B. Here, the magnetic gap means an air gap or air path. In Fig. 22A, the magnetic gap 105g' is formed by two magnets, and in Fig. 22B, the magnetic gaps 105g' are respectively formed by each magnet. Although Figs. 22A and 22B show a magnetic circuit including two-pole magnetized magnet 105', however, a two-pole magnetized magnet using a U shape, a three-pole magnetized magnet and a four-pole

magnetized magnet may be applied to the magnetic circuit.

In the above structure, the coil units 103 are bonded and fixed to the pair of side surfaces of the lens holder 101 that extend in parallel to the tracking direction. However,

5 a similar effect can also be obtained even in another structure in which, as shown in Fig. 23, there are completed two magnetic circuits each including at least one magnet 105 magnetized in two polarities in the focus direction F and, within each of the magnetic gaps 105g of the magnetic circuits, there are  
10 disposed focus coils 130f respectively wound around the side surfaces of the lens holder 101 as well as the tracking coils 130tr and tilt coils 130ti respectively mounted on the two side surfaces (which extend in parallel to the tracking direction T) of the lens holder 101. By the way, two magnetic circuit  
15 may be respectively include one magnet, as shown in Fig. 21.

Each focus coil 130f is a winding coil with the lens holder 101 as its winding frame and thus, when compared with a focus coil which is pattern formed on a printed circuit board, the focus coil 130f is easy to manufacture.

20 The tracking coil 130tr and tilt coil 130ti are respectively a coreless coil which is mounted on top of the focus coil 130f.

However, the tracking coil 130tr and tilt coil 130ti may also be pattern formed on a printed circuit board. Also, the tracking coils 130tr and tilt coils 130ti may also be winding coils  
25 in which, as shown in Fig. 24, coil winding frames 113 are

provided on and projected from the side surfaces (which extend in parallel to the tracking direction T) of the lens holder 101 and coils are respectively wound around these coil winding frames 113. Further, one of the tracking coil 130tr and tilt coil 130ti may be mounted on the focus coil 130f and the other may be wound around the coil winding frame 113.

The magnet 105 is magnetized in two polarities in the focus direction F by the boundary line 105b between the N and S poles of the magnet 105 and is bonded to the yoke 107 which is disposed on a yoke base 106.

The width W of the magnet 105 is determined such that, when, at the movable neutral position of the movable part movably supported in a cantilevered manner by the conductive elastic members 104, that is, at the self-weight position of the movable part in the focus direction F, as shown in Fig. 25, the lens holder 101 is arranged in the magnetic gap 105g, not only the right and left inner vertical sides A and C of the vertical sides A and C (which extend in parallel to the focus direction F) of the two tracking coils 130tr, which are disposed in the upper stage in the focus direction F as well as are disposed right and left in a row in the tracking direction T, but also the right and left outer vertical sides a' and c' of the vertical sides a' and c' (which extend in parallel to the focus direction F) of the two tilt coils 130tr which are disposed in the lower stage in the focus direction F as well as are disposed right

and left in a row in the tracking direction T can be respectively arranged within the magnetic gap 105g (which points out a gap existing within the width W of the two mutually opposing magnets 105). Also, the height H of the magnet 105 is determined such  
5 that, as shown in Fig. 25, the horizontal sides B and D (which extend perpendicularly to the focus direction F) of the tracking coils 130tr as well as the horizontal sides b' and d' (which extend perpendicularly to the focus direction F) of the tilt coils 130ti can be respectively disposed within the magnetic  
10 gap 105g (which points out a gap existing within the height H of the two mutually opposing magnets 105).

The boundary line 105b between the N and S poles of the magnet 105, as shown in Fig. 25, is situated downwardly of the lower sides B of the horizontal sides B and D (which extend  
15 perpendicularly to the focus direction F) of the tracking coils 130tr as well as midway between the lower sides b' and upper sides d' of the horizontal sides b' and d' (which extend perpendicularly to the focus direction F) of the tilt coils 130ti. The center of the magnet 105 is substantially coincident  
20 with the center of the lens holder 101.

The focus coils 130f are disposed upwardly and downwardly with the boundary line 105b between the N and S poles of the magnet 105 as the boundary line thereof. The upper and lower focus coils 130f are connected in series, while the directions  
25 of the currents of the upper and lower focus coils 130f are

reversed. The directions of magnetic lines of force in the two magnetic gaps 105g are reversed.

In Figs. 23 and 24, all sides of the tracking coils 130tr and tilt coils 130ti are mounted on one side surface (which extends in parallel to the tracking direction T) of the lens holder 1. However, this is not limitative but it is also possible to employ another structure; that is, the sides that are arranged within the magnetic gap 105g and are able to generate drive forces, for example, the vertical sides A, C (see Fig. 25) (which extend in parallel to the focus direction F) of the tracking coils 130tr, which, in case where currents are allowed to flow in the tracking coils 130tr, can generate drive forces in the same direction in the tracking direction T, are mounted on one side surface of the lens holder 1.

The lens holder 101 is disposed in the two magnetic gaps 105g and the other-side ends of the conductive elastic members 104 are penetrated through a wire base 108 and are fixed to a base plate 109 by soldering. Thanks to this, the focus coils 130f, tracking coils 130tr and tilt coils 130ti can be disposed within the magnetic gap 105g and, at the same time, the movable part including the lens holder 101 holding the objective lens 102 can be supported in a cantilevered manner so as to be movable with respect to the fixed part which includes the magnet 5, yoke base 106, yoke 107, wire base 108 and base plate 109.

In Fig. 23, in case where currents are allowed to flow

in the focus coils 130f, due to the current that flows in the magnetic gap 105g, in the focus coils 130f, there are generated drive forces in the focus direction F according to Fleming's left-hand rule.

5           In Fig. 25, in case where current are allowed to flow in the tracking coils 130tr, due to the currents (shown by arrow marks) that flow in the vertical sides A and C (which extend in parallel to the focus direction F) of the tracking coils 130tr, in the two tracking coils 130tr, there are generated  
10 drive forces in the same direction in the tracking direction T according to Fleming's left-hand rule; and, in case where currents are allowed to flow in the tilt coils 130ti, due to the currents (shown by arrow marks) that flow in the horizontal sides b' and d' (which extend perpendicularly to the focus  
15 direction F) of the tilt coils 130ti, in the two tilt coils 130ti, there are generated drive forces F' in the mutually reversed directions in the focus direction F according to Fleming's left-hand rule. Due to the reversed-direction drive forces F', there is generated moment around the center of gravity  
20 of the movable part, thereby being able to adjust the inclination of the lens holder 101 and thus the inclination of the objective lens 102.

          The above description relates to the structure in which the two tracking coils 130tr and two tilt coils 130ti are arranged  
25 right and left symmetrically in the tracking direction T, while

there are generated the drive forces in the same direction in the two tracking coils 130tr and there are generated drive forces in the reversed directions in the two tilt coils 130ti.

However, as shown in Fig. 26, the vertical side A (which extends  
5 in parallel to the focus direction F) of a tracking coil 130tr may be disposed within the width W of the magnet 105, and the vertical side C (which extends in parallel to the focus direction F) of the tracking coil 130tr may be disposed outside the width W of the magnet 105; and, at the same time, a tilt coil 130ti  
10 may be disposed shifted outside with respect to the center of the magnet 105 in the tracking direction T. Also, instead of the tracking coil 130tr, as shown in Fig. 25, there may be used two tracking coils 130tr; and, instead of the tilt coil 130ti, as shown in Fig. 26, there may be used two tilt  
15 coils 130ti. Further, the tracking coil 130tr, as shown in Fig. 26, may be one in number and the tilt coil 130ti, as shown in Fig. 25, may be two in number. In any of these structures, the weight of the objective lens drive apparatus can be reduced.

20 (Embodiment 3)

Now, Fig. 27 is a perspective view of a third embodiment of an objective lens drive apparatus according to the invention.

In Fig. 27, reference character 201 designates a lens holder,  
202 an objective lens, 203 a coil unit, and 205 a magnet,  
25 respectively.

The lens holder 201 is similar in structure to the lens holder 1 employed in the previously described first embodiment.

The coil unit 203 comprises a required number of printed circuit boards 203p which are laminated one on top of another, while each of the printed circuit board 203p comprises a tracking coil 203t and four focus coils 203fl and 203fr. The tracking coil 203t is situated at the center of the printed circuit board 203p, while the focus coils 203fl and 203fr are arranged in two upper and lower stages and are disposed right and left with respect to the position of the objective-lens-optical-axis-direction center of gravity of a movable part including the lens holder 201 holding the objective lens 202, that is, on the right and left sides of the tracking coil 203t. The number of the focus coils 203fl and the number of the focus coils 203fr may also be one respectively. And, since currents are supplied to the left and right focus coils 203fl and 203fr individually, the left and right focus coils 203fl and 203fr are not connected in series but they are independent of each other.

The foregoing description relates to the structure in which the left and right focus coils 203fl, 203fr and tracking coil 203t are disposed on the same printed circuit board 203p.

However, as a modification of the third embodiment, the left and right focus coils 203fl, 203fr and tracking coil 203t may also be disposed separately on two printed circuit boards.

In this modification as well, the number of focus coils to be disposed on a printed circuit board is even and the number of tracking coils to be disposed on a printed circuit board is one.

5       The coil unit 203 is inserted into and bonded to the notch portions 201a of the lens holder 201 and is thereby fixed to the lens holder 201. In the two ends (in the tracking direction T) of the coil unit 203, there are formed six V-grooves 203v, while the one-side ends of six conductive elastic members 204  
10   are respectively fixed to the six V-grooves 203v by solders 203h. The conductive elastic members 204, which are used as lead wires, consist of four members 204 (2 x 2) for focus coil driving and two members 204 for tracking coil driving, a total of six members 204.

15       By the way, four conductive elastic members 204 are enough to elastically hold the lens holder 201 serving as the movable part and, therefore, in case where four conductive elastic members 204 are employed to hold the lens holder 201, lead wires (not shown) are to be connected to the remaining coils.

20       The magnetic circuit employed in the present embodiment is similar to the magnetic circuit employed in the first embodiment and shown in Fig. 6. Further, the magnetic circuit may be include one magnet, as shown in Figs. 9 and 10. In this case, the boundary line between the N and S poles is situated  
25   at the center of the magnet 5 in the tracking direction T as





been obtained using the inclination detect sensor or using the reproduction signal of the optical pickup, are input to a control circuit shown in Fig. 29; and, the control circuit calculates the optimum currents  $I_l$  and  $I_r$  which can urge the focus coils 203fl and 203fr shown in Fig. 28 to thereby correct the focus error and tilt error at the same time, and then the control circuit outputs the thus calculated currents  $I_l$  and  $I_r$ . The objective lens drive apparatus, which is a controlled object, not only executes a focus servo due to a force which is the sum of drive forces  $F_l$  and  $F_r$  generated in response to the currents  $I_l$  and  $I_r$  and shown in Fig. 30A and also which moves in the focus direction  $F$ , but also executes a tilt servo due to the moment  $M = F_l \times d - F_r \times d$  that is generated around the center of gravity  $G$  of the lens holder 201 due to the difference between the drive forces  $F_l$  and  $F_r$ . Here,  $d$  expresses the distance between the center of gravity  $G$  of the lens holder 201 and the focus coils 203fl, 203fr.

Now, Fig. 30B shows a case in which, differently from Fig. 30A, the drive forces  $F_l$  and  $F_r$  are generated in the mutually opposite directions. In this case, a force, which is going to move in the focus direction  $F$ , is  $F_l + (-F_r)$ , while a tilt is  $F_l \times d - (-F_r \times d)$ . At any rate, the objective lens drive apparatus executes a focus driving operation with a function of  $(F_l + F_r)$  and executes a tilt driving operation with a function of  $(F_l - F_r)$ .





individually, they are not connected in series but are connected independent of each other.

In this structure, the focus coil 203f and tracking coils 203tu, 203td are disposed on the same printed circuit board 203p. However, the focus coil 203f and tracking coils 203tu, 203td may also be disposed separately on two different printed circuit boards. In this case as well, the numbers of focus coils and tracking coils to be disposed on a printed circuit board are respectively one and even.

The width W of the magnet 205 is determined such that, at the movable neutral position of the movable part movably supported in a cantilevered manner by the conductive elastic members 204, that is, at the self-weight position of the movable part in the focus direction F, as shown in Fig. 32, when the coil unit 203 is arranged within the magnetic gap 205g, the right and left inner vertical sides C and A of the vertical sides A and C (which extend in parallel to the focus direction) of the two upper-stage right and left tracking coils 203tu as well as the two lower-stage right and left tracking coils 203td can be respectively disposed within the magnetic gap 205g (which points out a gap existing within the width W of the mutually opposing magnets 205). Also, the height H of the magnet 205 is determined such that, as shown in Fig. 32, not only the horizontal sides b and d (which extend perpendicularly to the focus direction F) of the focus coil 203f situated at

the center of the print circuit board 203p, but also the upper  
sides D of the horizontal sides B and D (which extend  
perpendicularly to the focus direction F) of the upper-stage  
tracking coils 203tu and the lower sides B of the horizontal  
5 sides B and D (which extend perpendicularly to the focus direction  
F) of the lower-stage tracking coil 203td can be respectively  
disposed within the magnetic gap 205g (which points out a gap  
existing within the height W of the mutually opposing magnets  
205).

10 The boundary line 205b between the N and S poles of the  
magnet 205, as shown in Fig. 32, is situated midway not only  
between the lower side b and upper side d of the horizontal  
sides b and d (which extend perpendicularly to the focus direction  
F) of the focus coil 203f but also between the lower sides  
15 B of the horizontal sides B and D (which extend perpendicularly  
to the focus direction F) of the upper-stage tracking coils  
203tu and the upper sides D of the horizontal sides B and D  
(which extend perpendicularly to the focus direction F) of  
the lower-stage tracking coils 203td. And, the center of the  
20 magnet 205 is substantially coincident with the center of the  
coil unit 203.

A tilt error signal and a tracking error signal, which  
have been obtained using an inclination detect sensor or using  
the reproduction signal of an optical pickup, are input to  
25 a control circuit which is similar to the control circuit shown

in Fig. 29; and, the control circuit calculates the optimum currents  $I_u$  and  $I_d$  which can urge the tracking coils 203tu and 203td shown in Fig. 32 to thereby correct the tracking error and tilt error at the same time, and then the control

5 circuit outputs the thus calculated currents  $I_u$  and  $I_d$ . The objective lens drive apparatus, which is an controlled object, not only executes a tracking servo due to a force which is the sum of driving forces (not shown) generated in response to the currents  $I_u$  and  $I_d$  and also which moves in the tracking

10 direction  $F$ , but also executes a tilt servo due to the moment that is generated around the center of gravity of the lens holder 201 due to the difference between the driving forces.

In case where the focus coil 203f is urged, due to the currents (shown by arrow marks in Fig. 32) that flow in the

15 horizontal sides  $b$  and  $d$  which extend perpendicularly to the focus direction  $F$  of the focus coil 203f in Fig. 32, there are generated driving forces in the same direction in the focus direction  $F$ , so that the objective lens 202 can be moved in the focus direction  $F$  according to the surface vibration of

20 the record medium.

In this embodiment, the magnet 205 has two poles magnetized in the focus direction  $F$  or in the tracking direction  $T$ . However, this is not limitative but, for example, as shown in Fig. 33, there can also be employed a magnet 205 including two

25 magnet sections each having two poles magnetized in the tracking

direction and respectively disposed in upper and lower stages in the focus direction, thereby providing the magnet 205 having four poles magnetized. In this case, as shown in Fig. 33, two tracking coils 203tu are disposed in the upper and lower portions of the magnet 205, that is, in the first and second quadrants of the magnet 205 and in the third and fourth quadrants of the magnet 205; and, currents having mutually opposite directions are allowed to flow through the two tracking coils 203tu and, due to the force that is the sum of the upper and lower drive forces  $F_u$  and  $F_d$  respectively generated in the two tracking coils 203tu and moves in the tracking direction  $T$ , there can be carried out a tracking servo control. Also, as shown in Fig. 34, two focus coils 203fl, 203fr are disposed in the right and left portions of the magnet 205, that is, in the first and fourth quadrants of the magnet 205 and in the second and third quadrants of the magnet 205; and, left and right currents  $I_l$  and  $I_r$  ideally suitable for simultaneous correction of focus errors and tilt errors output from the control circuit are allowed to flow through the two focus coils 203fl, 203fr, whereby a focus servo control is executed due to the force that is the sum of left and right drives forces  $F_l$  and  $F_r$  respectively generated in the two focus coils 203fl, 203fr and moves in the focus direction  $F$  and, at the same time, a tilt servo control is carried out due to the moment generated around the center of gravity  $G$  caused by

the difference between the left and right forces  $F_l$  and  $F_r$ .

Also, although not shown, upper and lower currents  $I_u$  and  $I_d$  ideally suitable for simultaneous correction of tracking errors and tilt errors output from the control circuit are  
5 allowed to flow through the upper and lower tracking coils 203tu, 203td respectively disposed in the first and second quadrants of the magnet 205 and in the third and fourth quadrants of the magnet 205, whereby a tracking servo control is executed due to the force that is the sum of upper and lower forces  
10  $F_u$  and  $F_d$  respectively generated in the two tracking coils 203tu, 203td and moves in the tracking direction  $F$  and, at the same time, a tilt servo control is carried out due to the moment generated around the center of gravity  $G$  caused by the difference between the upper and lower forces  $F_u$  and  
15  $F_d$ .

In case where the magnet 205 has four poles magnetized, when compared with the magnet having two poles magnetized, the number of coils is reduced from five down to four, thereby being able save the coils used. Also, in the case of the magnet  
20 205 having two poles magnetized, the portions of the magnet 205, which are opposed to the portions where the coil drive forces are generated, must be disposed outside the magnetic gap 205g (that is, the b and d sides of 203fl and 203fr in Fig. 28; the A and C sides of 203tu and 203td in Fig. 32).  
25 On the other hand, in the case of the magnet 205 having four



of the flange portion of the I-like shape and in the N poles;  
 and, left and right currents  $I_l$  and  $I_r$  ideally suitable for  
 simultaneous correction of focus errors and tilt errors output  
 from the control circuit part are allowed to flow through  
 5 the two focus coils 203fl, 203fr, whereby a focus servo control  
 is executed due to the force that is the sum of left and right  
 drives forces  $F_l$  and  $F_r$  respectively generated in the two  
 focus coils 203fl, 203fr and moves in the focus direction  
 $F$  and, at the same time, a tilt servo control is carried out  
 10 due to the moment generated around the center of gravity  $G$   
 caused by the difference between the left and right forces  
 $F_l$  and  $F_r$ .

When the magnet 205 is structured such that it has three  
 poles magnetized, as shown in Fig. 36, one pole (for example,  
 15 S pole) is formed so as to have an H-shaped front surface  
 and the other two poles (for example, N poles) each having  
 a quadrilateral-shaped front surface are inserted into the  
 other space of one pole to thereby provide a magnet having  
 a quadrilateral-shaped front surface as a whole. In this case,  
 20 as shown in Fig. 36, two focus coils 203fu, 203fd are disposed  
 in the upper and lower portions of the magnet 205, that is,  
 in the web portion of the H-like shape and in the N poles  
 and currents having mutually opposite directions are allowed  
 to flow through the two focus coils 203fu, 203fd, whereby  
 25 a focus servo control is carried out due to the force that

is the sum of the upper and drive forces  $F_u$  and  $F_d$  and moves in the focus direction  $F$ . Also, as shown in Fig. 36, upper and lower currents  $I_u$  and  $I_d$  ideally suitable for simultaneous correction of tracking errors and tilt errors output from the control circuit part are allowed to flow through the four tracking coils 203tu, 203td are disposed in the right and left portions of the flange portion of the H-like shape and in the N poles, whereby a tracking servo control is executed due to the force that is the sum of upper and lower drives forces  $F_u$  and  $F_d$  respectively generated in the tracking coils and moves in the tracking direction  $T$  and, at the same time, a tilt servo control is carried out due to the moment generated around the center of gravity  $G$  caused by the difference between the upper and lower forces  $F_u$  and  $F_d$ .

In this embodiment, the tilt servo is carried out using the four focus coils 203f or four tracking coils 203tr. However, when the tilt servo control is executed using two focus coils 203f, as shown in Fig. 37, there is used a magnet having three poles magnetized: that is, one pole (for example, S pole) is formed so as to have a T-shaped front surface and the other two poles (for example, N poles) each having a quadrilateral-shaped front surface are inserted into the other space of one pole to thereby provide a magnet having a quadrilateral-shaped front surface as a whole. In this case, two tracking coils 203tl, 203tr are disposed in the central

portion of the magnet 205, that is, in the vertical portion  
of the T shape and in the N poles; and, two focus coils 203fl,  
203fr are disposed in the left and right portions of the magnet  
205, that is, in the horizontal portion of the T-like shape  
5 and in the N poles. And, left and right currents  $I_l$  and  $I_r$   
ideally suitable for simultaneous correction of focus errors  
and tilt errors output from the control circuit part are allowed  
to flow through the two focus coils 203fl, 203fr, whereby  
the focus servo control is executed due to the force that  
10 is the sum of left and right drives forces  $F_l$  and  $F_r$  respectively  
generated in the two focus coils 203fl, 203fr and moves in  
the focus direction F and, at the same time, the tilt servo  
control is carried out due to the moment generated around  
the center of gravity G caused by the difference between the  
15 left and right forces  $F_l$  and  $F_r$ .

In the case of the magnet having three poles magnetized,  
when compared with the magnet having two poles magnetized,  
similarly to the magnet having four poles magnetized, the  
use rate of the coils can be enhanced.

20 Referring to the coil unit, whether the magnet has three  
or four poles magnetized, similarly to the magnet having two  
poles magnetized, the coil unit includes a plurality of piled-up  
printed circuits of two types: that is, one type includes  
one or more focus coils 203f mounted thereon; and, the other  
25 type includes one or more tracking coils 203t mounted thereon.

Also, the coil unit may also include a plurality of piled-up printed circuits each including one or more focus coils 203f and one or more tracking coils 203t mounted thereon.

Further, the system that can execute the tilt driving  
5 by the control unit having focus coil and tracking coil in the third embodiment can be applied to the objective lens drive apparatus according the second embodiment shown in Figs. 20 and 21.

Furthermore, in the above first to third embodiments,  
10 the objective lens driving apparatus using the magnet magnetized in two, three or four polarities is explained, however, the present invention is not limited to this, a magnet magnetized in further multi-polarities may be applied to the objective lens driving apparatus.

As has been described heretofore, according to the first  
15 aspect of the invention, there is provided an objective lens drive apparatus in which a coil unit with a focus coil, a tracking coil and a tilt coil mounted thereon is disposed within the same magnetic gap of a magnetic circuit including at least  
20 one magnet magnetized in multi-polarities. In the present objective lens drive apparatus, the inclination of an objective lens can be adjusted using the magnet for focus and tracking driving, which eliminates the need for provision of a magnet which is exclusively used to adjust the inclination of the  
25 objective lens. Therefore, according to the first aspect of

the invention, it is possible to prevent an increase in the cost as well as an increase in the size of the objective lens drive apparatus, which are otherwise caused by the adjustment of the inclination of the objective lens.

5       Also, according to the second aspect of the invention, there is provided an objective lens drive apparatus in which there are completed two magnetic circuits each including at least one magnet magnetized in multi-polarities and, within the magnetic gap of each of the two magnetic circuits, there  
10 is disposed a coil unit with a focus coil, a tracking coil and a tilt coil mounted thereon. In the present objective lens drive apparatus, the inclination of an objective lens can be adjusted using the magnets for focus and tracking driving, which eliminates the need for provision of a magnet which is  
15 exclusively used to adjust the inclination of the objective lens. Therefore, according to the second aspect of the invention, it is possible to prevent an increase in the cost of the objective lens drive apparatus as well as an increase in the size thereof, which are otherwise caused by the adjustment of the inclination  
20 of the objective lens.

Further, according to the third aspect of the invention, there is provided an objective lens drive apparatus in which a coil unit with a plurality of focus coils and a tracking coil mounted thereon is disposed within the same magnetic gap  
25 of a magnetic circuit including at least one magnet magnetized

in multi-polarities, currents are supplied respectively to the plurality of focus coils included in the coil unit to thereby be able to execute focus servo due to the sum of drive forces generated in response to the supply of the currents, and moment  
5 is generated around the center of gravity of a movable part due to the difference between the drive forces to thereby be able to adjust the inclination of an objective lens simultaneously with the focus servo. In the present objective lens drive apparatus, using the right and left focus coils, not only the  
10 focus servo but also the adjustment of the inclination of the objective lens can be carried out, which eliminates the need for provision of a coil and a magnet which are exclusively used to adjust the inclination of the objective lens. Therefore, according to the third aspect of the invention, it is possible  
15 to prevent an increase in the cost of the objective lens drive apparatus as well as an increase in the size thereof, which are otherwise caused by the adjustment of the inclination of the objective lens.